AEI

Electrical Distribution

THE NEWS MAGAZINE OF THE CABLE AND CONSTRUCTION (CABLES & LINES) DIVISIONS OF ASSOCIATED ELECTRICAL INDUSTRIES LTD

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EDITORIAL

RAILWAY ELECTRIFICATION is in the news. Just behind us is the British Railways' 25kV Electrification Conference at which delegates from forty-three countries heard for themselves the impressive progress made in Britain's new rail electrification programme.

Lord Chandos, vice-president of B.E.A.M.A., who prepared a recorded talk for overseas radio stations as a "curtain raiser" for the conference, discussed the important contribution of industry to this project and pointed out how the scheme provides a spur to technical development.

Associated Electrical Industries, of which Lord Chandos is chairman, are playing a considerable part in the 25kV programme. Evidence of this was seen on the A.E.I. displays at Battersea wharf, in the exhibition which ran concurrently with the Electrification Conference.

Cables manufactured and installed by A.E.I. engineers carry the power for much of the 25kV development so far accomplished. 24 000yd of A.E.I. 25kV solid type cables are "in service" on the Manchester–Crewe lines—opened last month by Mr Marples, Minister of Transport, as Britain's first 25kV main-line electric service. More miles of cable, this time of the A.E.I. 25kV oil-filled design, have been installed for part of the £16 million Glasgow Suburban electrification. In our next issue we hope to present, along with other news of interest, the story of these two contracts.

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OUR COVER PICTURE

Cover picture this month shows A.E.I. cabling in progress in the new C.E.G.B. Staythorpe "B" power station, Nottinghamshire. These cables are being installed on the main riser which carries three-quarters of the main and control cabling to generating sets 1 and 2 from the basement. See page 36.

News in brief...

Huge New Steelworks Cable Contract

A CONTRACT VALUED at more than £½ million for the 33kV and 11kV cabling of the new Spencer steelworks being built by Richard Thomas and Baldwin at Newport, Monmouthshire, has been awarded to Associated Electrical Industries. Their Construction (Cables and Lines) Division has commenced work on site.

The contract for the supply and installation of these cables comprises 15 miles of 3-core and approximately 2½ miles of single-core 33kV solid type cables, 20 miles of 11kV 3-core cables, and 4 miles of 11kV single-core cables. All cables will be sheathed with p.v.c. overall.

Other A.E.I. equipment which will be used at Spencer works includes six steelwork process line drives, each of which employs a d.c. Ward-Leonard system with closed-loop speed control, using the most recent developments in the applications of electronics to servo systems.

An idea of the magnitude of the Richard Thomas and Baldwin project can be gained from the scope of the civil engineering works for the foundations. Construction has been going on for a year on the four-mile-long marshland site at Newport. The whole works is being built on 38ft deep reinforced concrete piles and it is estimated that about 8 million tons of shale "fill" will be used.

In this steelworks the new Linz and Donawitz (LD) process for steel making will be used, to obtain from pig-iron a higher quality steel than that resulting from the Bessemer process.

The A.E.I. power cables are thus part of a plan to introduce a new period of advanced technique and increased productivity to Britain's steel-making industry.

Spencer works is named after Mr Henry F. Spencer, managing director of Richard Thomas & Baldwins Ltd. Mr Spencer is a member of the Council and Executive Committee of the British Iron and Steel Federation.

Another Supergrid Construction Job

A DETAILED SURVEY of 26¼ miles of route for the erection of the Whitfield–Rugeley supergrid line is now being undertaken by the A.E.I. Construction Division

A.E.I. were awarded the contract for the line in June of this year by the Central Electricity Generating Board, Midlands Division. The contract is worth about £350 000.

This 275kV line will be strung with twin 0·175sq.in. steel-cored aluminium conductors. The route from Whitfield, five miles north of Stoke-on-Trent, passes east of that town, and south to Rugeley, near Stafford. Construction work is due to start early next year.

Mr S. L. Crafford–manager of new East Anglian District Office

Mr S. L. Crafford.

FOLLOWING THE INTEGRATION of the former district and branch office systems of Siemens Edison Swan Ltd and W. T. Henley's Telegraph Works Co. Ltd (both now part of A.E.I. Woolwich Group), a new District Office has been formed. Known as the East Anglian District Office, it represents the Woolwich Group in Norfolk, Suffolk, and the northern half of Essex. It has been formed from the Colchester, Ipswich, and Norwich Branch Offices, which have been detached from the London District Office.

Mr S. L. Crafford has been appointed manager of the East Anglian District Office. He joined W. T. Henley's Telegraph Works Co. in 1924 and in 1926 assisted in establishing Henley's sales promotion department, of which he subsequently took charge. Mr Crafford was appointed to Henley's Colchester Branch Office in 1946. For the present he will continue to operate from the Colchester Office in his capacity of East Anglian District Office Manager.

Clyde Supergrid Crossing for A.E.I.

THE SOUTH OF SCOTLAND Electricity Board has awarded to Associated Electrical Industries the contract for the supply and erection of crossing towers, anchor towers, and conductors for the crossing of the river Clyde by the 275kV supergrid near Erskine Ferry near Glasgow.

The crossing towers, of Blaw-Knox design, will be 371ft high with a 60ft square base. They are designed to carry twin 0·4sq.in. steel-cored aluminium conductors and will allow a specified clearance of 240ft to high-water mark of the Clyde. Distance between anchor towers is 0·65 mile in a direct line.

A.E.I. Construction (Cables and Lines) Division will carry out the work, which is scheduled for completion in December 1961.

Major Extension to Chilterns' Sub-Area

33kV feeders from Manton Lane cross the Ouse to extend supply to new factory

AMONG NEW BUILDING development in Bedford is a large factory for Texas Instruments Ltd. To afford an adequate electricity supply to the factory, the Eastern Electricity Board have extended their distribution system by the installation of two 33kV feeders from the existing Austin Canons 132kV grid substation to a new substation at Manton Lane, adjacent to the factory.

At Manton Lane two 20MVA 33/11kV transformers have been installed by the Board to supply the loads of the factory and of local consumers in the area, an arrangement which also called for additional 11kV cabling to reroute part of local circuits into the substation.

The supply, laying, and jointing of the 33kV feeders, 11kV and multicore cables were recently completed by A.E.I. engineers of the Construction Division.

The duplicate feeders were 0·35sq.in. 33kV 3-core oil-filled cables, lead sheathed and served, of conventional construction, laid with duplicate pilot/telephone cables of 7/·029in. 6-core + 1/·044in. 22 pair polythene insulated PVC SWA PVC construction. The cables followed a route length of about 2¼ miles over low-lying land which contained several interesting crossings.

One of these was the crossing of the river Ouse in the first section of the cables to be laid from Austin Canons substation. During the preliminary skin-diving operations, the river, about 60ft wide and 15ft deep at this point, was found to have an unobstructed muddy bottom. The main cable trenches, however, had to stop short of the river banks on either side in order to prevent complete flooding of the whole section. The laying technique adopted was to divide the main cable trench into two for a short distance before the banks were reached, and lay one feeder and pilot cable in each arm of the Y thus formed. Where these sub-trenches approached the banks, a short length of trench was dug back from

Easing the first feeder round a slight bend in the trench after pulling it across the river. Eventually, this cable was transferred to the three trenches seen radiating from the bottom of the illustration. Similarly, feeder 2 was pulled into the right-hand trench and transferred to the centre trench. By this means a reasonably straight pull was obtained, although the final position of the cables entailed two right-angled bends at this point in each feeder.

By means of concrete-filled sacks the diver ensured that the cables were bedded down securely on the river bed.

the river. This immediately flooded, but a plug of untouched river bank was left to bar the water from further invasion of the trenches.

Each feeder and pilot cable was then run out for its full length and bedded down on the river bottom by means of concrete-filled sacks. Successful laying and bedding of the cable were ensured by a diver using conventional diving gear—much to the interest of many small boys in the locality! Concrete-filled sacks and tamped-down backfill were then used to plug the short excavations in the river bank, the earth "plug" was removed and the cables were straightened in the trenches before backfilling. These operations were made more complex by the necessity to draw the new cables under several power cables which had been laid, in the past, parallel to the river along one bank.

The remainder of the cable route was covered without incident, along secondary roads and across rough open ground and sports fields, until the 4-track main London–Edinburgh railway was reached. Here the cable-laying gangs found two 6in. and two 4in. pipes installed ready to take the cables. A few days before, while carrying out the thrust boring for the pipes, the boring crew had struck, the impacted hard core with which the railway embankment had been made up. Eventually, after the borer-head had been deflected from its straight path several times at various levels, the pipes were installed at a depth of approximately 10ft.

The last sections to Manton Lane substation entailed laying in farmland and the crossing of the busy Clapham Road, which was accomplished without resort to headings.

Several hundred yards of 0·25sq.in. 11kV 3-core PLYSWS cables were also laid in the vicinity of Manton Lane substation, with over 3 000yd of associated multicore cables to serve local circuits.

Education Schemes Integrated

FULL INTEGRATION OF the Henley Education Scheme with the A.E.I. (Woolwich) Educational Department has now been accomplished. Its apprenticeship schemes were, in general, organized on parallel lines to those in Siemens Edison Swan, though there were many differences in detail. It will, therefore, be some time before all the schemes can be completely merged.

The Cable Division and the Construction (Cables and Lines) Division now have a comprehensive system of training facilities. This year, for the first time, recruitment of professional apprentices will fall under three schemes which are already part of the Manchester and Rugby groups' system. These are: "sandwich" courses for student apprentices; a year's training for pre-university apprentices who will, after full-time university attendance, return for a final year's post-graduate training; thirdly, men who for the most part went direct to university from school will be recruited for two years' post-graduate training.

Earthing in Power Systems

by A. SALZMANN, Dipl.Ing., A.M.I.E.E.

PART I

This article, presented in two parts, is a review of neutral earthing in high-voltage transmission.

THE OBJECTS OF neutral earthing are (a) reduction of the fault current to a small value without jeopardizing the operation of the protective gear or, alternatively, elimination of the fault current at the location of fault, and (b) maintenance of voltage stability on the healthy phases during periods of system disturbances to avoid the danger of overstressing the insulation of various transmission elements.

In the earlier days of power transmission, earthing problems were non-existent because the fault current between line to line was sufficiently large to operate the protective relays and arcing ground faults were self-clearing owing to the small capacitive current. As power systems grew larger and higher operating voltages were applied, system operation via the insulated neutral became obsolete, as arcing earth-faults caused by large capacitance current produced dangerous overvoltages on the healthy phases, causing double earth-faults on different sections and phases of the system. These cross-country faults were responsible for indiscriminative operation of the protective gear and resulted in disconnection of a larger section of the system than would have been necessary, initially, to clear single line-to-earth faults with earthed neutral.

However, the solution of this problem is not an easy one and remains controversial in many countries. The question which arises is not whether the system neutral should be earthed, but *which is the best method of neutral earthing*.

Power systems may have their neutral earthed in the following ways:

1. Solidly earthed. No resistance is inserted intentionally between neutral point and earth.
2. Partially solidly earthed. Limitation of earthing to one transformer and one station of the transmission system (see Fig. 1, station "A").
3. Resistance earthed. Resistance is placed intentionally in the connection between neutral and earth.
4. Reactance earthed. (Tuned or Untuned.) Iron-cored reactor inserted between neutral point and earth.
5. Artificially earthed. Creating a neutral point *via* earthing transformer.

In this country solid neutral earthing is standard practice for transmission lines operating at voltages in excess of 66kV. For systems operating at 33kV or less, solid and resistance earthing are predominant. Resonant neutral earthing using arc-suppression coils (A.S.C.) is

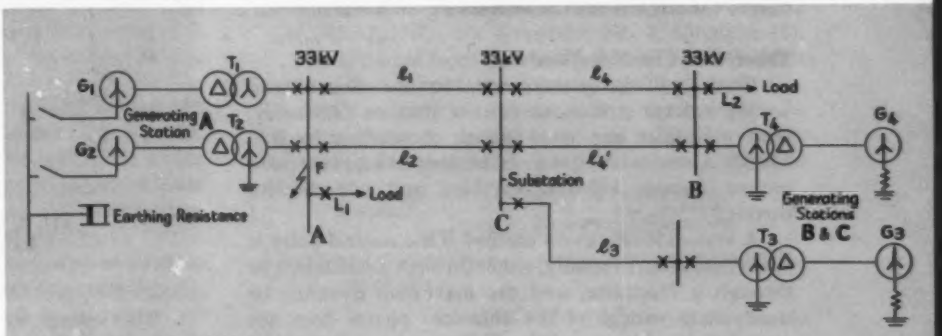

Fig. 1. Circuit diagram of a large interconnected transmission system having neutrals solidly earthed.

Fig. 1a. Single-line diagram.

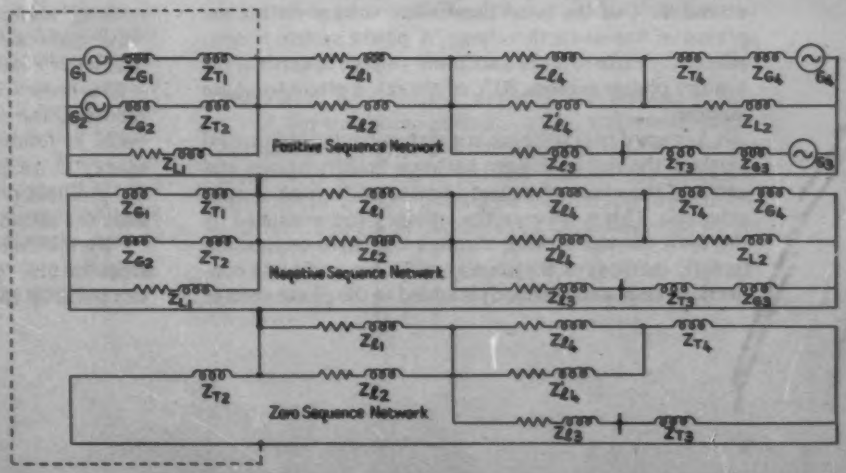

Fig. 1b. Phase-sequence networks. Interconnection for a line-to-earth fault. Busbars A.

popular, particularly for systems operating at or below 33kV. However, there are two school of thought regarding the application of A.S.C. The first utilizes short-time rated coils for clearing transient faults only and leaves the isolation of persistent earth-faults to the conventional protective gear, or, alternatively, employs sensitive wattmetric relays in conjunction with time relays; the second uses continuous rated coils for clearing both transient and persistent faults. In the event of a persistent fault the coil remains in circuit until arrangements can be made to isolate the faulty section by hand.

In fact, in Great Britain the task of the A.S.C. is primarily to deal with single line-to-earth transient faults. However, there is a tendency in most of the countries in Europe lately, where resonant neutral earthing is predominant, to limit A.S.C. earthing to transmission systems operating with voltages below 110kV. Bearing in mind that the arc-suppression coil has to perform a dual function in that it has to reduce the fault current to a small value and it has to limit the rate of rise of the recovery voltage after the arc is extinguished, it has been found that the coil will fail to perform these functions in networks operating with voltages from 110kV to 400kV. This is owing to (a) as corona losses increase the residual current in the fault path becomes quite large, particularly under bad weather conditions, and (b) increased system mileage, when the large capacitance current persistent in the arc path gives rise to the conditions known as "arcing ground". Cyclic charging and discharging of the system capacity through the fault are accompanied by oscillatory transients with an amplitude several times the steady-state voltage, consequently exposing the system insulation to excessive dielectric stresses.

Theoretical Considerations[1,2]

Earthing of the system neutral has the effect of converting voltage stresses to current stresses. Obviously, both quantities are inter-related. According to B.S. 116:1952, neutral earthing can be divided into two main groups, namely effective earthing and non-effective earthing.

A system is effectively earthed if the neutral point is connected to earth solidly, either through a resistance, or through a reactance, and the maximum dynamic or steady-state voltage of the unfaulted phases does not exceed 80% of the rated line-to-line voltage during the period of line-to-earth voltage. A power system is non-effectively earthed if the maximum voltage to earth of the healthy phases exceeds 80% of the rated phase-to-phase voltage.

As regard overvoltages in a system having the neutral earthed, the rise in voltage between healthy phases and earth in the event of a single line-to-earth fault is considerable. This is because the voltage drop produced by the fault current flowing through the earth connection (solidly earthed) or the neutral resistance and earth connection (resistance earthed) is added to the phase voltage of the sound phases. Further, a large current flowing through the loop "faulty phase—earth-fault path" with the latter coupled inductively to the healthy phases produces an additional voltage between unfaulted lines and earth. Where this voltage is additive, the 50c/s overvoltage of the sound phases becomes larger.

The second type of overvoltage, persisting for a few thousand microseconds and caused by arcing ground faults (transient overvoltage) or switching operations (surges) subsequently to fault removal, is also a function of the method of neutral earthing. Any change of system conditions is accompanied by oscillatory transients. An explanation of this phenomenon can be found in oscillations set up by the capacitance and inductance of the transmission elements, assuming the damping effect of the circuit resistance is negligible.

As an illustration, let us consider a single-phase simplified circuit representing a transmission system (see Fig. 2). We assume a grounding arc flash-over in free air caused by overvoltages or by branches of trees blowing into the overhead lines. If the arc is extinguished at the instant of "current zero", the voltage tending to appear across the fault space is at its maximum value, because of the quadratic relationship between current and voltage. The system capacitance C, no longer at the instant of "current zero" shunted by the fault, must be charged to this value. Charging the capacitance through the inductance L results in oscillatory current, and hence transient voltages across the fault path.

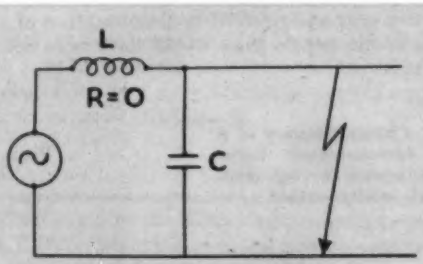

Fig. 2. Equivalent circuit diagram for a transmission system.

This voltage, denoted by V_{RR}, and known as the restriking voltage, will oscillate around the 50c/s voltage wave and reach a peak value about twice normal peak. The latter tends to cause breakdown of the fault space if it rises faster than the dielectric strength of the arc space, recovers, and makes the arc persistent for the next half-cycle. It follows that owing to ionization in the fault space, the arc path is still conducting if sufficient potential gradient (volt/inch) is available to maintain the arc after the instant of "current zero".

By multiple restrike the transient voltage persisting from the first "current zero" up to the final arc extinction can build up to a very high value. The natural frequency

$f_n=1/\sqrt{2\pi CL}$ of the oscillation is a function of both inductance L and capacitance C, assuming circuit resistance $R=0$, and it varies inversely as the square root of the product $C\times L$, neglecting the damping effect of the resistance. Since L is mainly determined by the generating capacity and C by the length of the feeders (being inversely proportional), a system with small capacitance may cause very high natural frequencies and hence a rapid restriking voltage rise because the time between the peak values is extremely short.

From the foregoing notes it follows that the system capacitance has a great effect on transient overvoltages while a single line-to-earth fault exists. Any circuit change that produces transient voltages involves the arc path. If the arcing occurs in the oil circuit-breaker, say, subsequently to fault removal, the produced transient voltages are called switching surges. For example, a solid line-to-earth fault involving, say, phase R is cleared by opening the 3-phase oil circuit-breaker but, with arcing, pole Y is involved and consequently an arcing ground fault is established. In this case the conditions are similar to those illustrated in Fig. 2.

It should be emphasized that the magnitude of switching overvoltages depends on both circuit-breaker design and the constants of the circuit to be interrupted. It is important to restore the dielectric strength of the arc path at the instant of "current zero" quicker than the rate of rise of the restriking voltage (RRRV volts/microseconds). A high RRRV means that the arc path has no time to cool and de-ion sufficiently and consequently it may cause the arc to restrike. The latter is likely to restrike if the voltage across the contacts rises faster than the recovery of the dielectric strength of the arc space. Thus circuit-breakers may become unsuitable for duty at certain locations because they are not able to cope with the increased RRRV.

Generally, the magnitude of the transient voltage will depend also on the method of neutral earthing. It can be assumed that the ratio of the highest peak value of the overvoltage to the peak value of phase-to-neutral will not exceed five for an insulated or resonantly earthed system, and three for a resistance-earthed system.

As an illustration, let us consider a system earthed *via* reactance. As the fault current is predominantly lagging, the transient voltage can be reduced if the neutral reactance is so chosen that the lagging current cancels the leading capacitance current, thus reducing the total fault current to a small value in phase with the system voltage. At the instant of "current zero" the voltage across the fault space will also be about zero and will rise at a slow rate of the normal 50c/s wave and possibly will not restrike. In fact this is the main reason, as we will see later, for earthing the neutral through an arc-suppression coil —to limit the transient overvoltage. Similar conditions arise in solidly and resistance-earthed networks, assuming that the heavy fault current is predominantly lagging, but the transient overvoltages become less severe.

Calculation of fault currents and fault voltages

The best method of calculating fault currents and dynamic or steady-state overvoltages in relation to neutral earthing is by the application of symmetrical components (see Appendix No. 1). For a line-to-earth fault the current is equal to

$$I_F=3V^1/(Z_1+Z_2+Z_0+3R_F) \quad \ldots\ldots(1)$$

where V^1=phase voltage; R_F=fault resistance; Z_1, Z_2, Z_0 are combined positive, negative, and zero phase-sequence impedances of the system viewed from the position of the fault and shown in Fig. 1. All the values are expressed in per unit (see Appendix No. 2).

For a 3-phase fault clear to earth the 3-phase fault current is equal to

$$I_{3\phi}=V^1/Z_1 \quad \ldots\ldots(2)$$

For a resistance-earthed system and a line-to-earth fault we have to substitute in equation 1 for

$$Z_0=(R_0+3R_N)+jX_0 \quad \ldots\ldots(3)$$

where R_0=combined zero sequence resistance of the transmission elements, R_N=neutral earthing resistance, and X_0=combined zero sequence reactance of the transmission elements. Similarly, for a reactance-earthed system we have to substitute for

$$Z_0=R_0+j(X_0+3X_N) \quad \ldots\ldots(4)$$

where X_N=neutral earthing reactance. We notice that the effective zero phase-sequence quantities must be three times the real value of neutral resistance R_N, neutral reactance X_N, and fault resistance R_F. The reason for this is that the voltage between neutral to earth, V_N, is equal to $V_N=I_FR_N=3I_{R0}R_N=I_{R0}(3R_N)$. The same applies to line-to-earth faults at the fault location $V_F=I_FR_F=3I_{R0}R_F=I_{R0}(3R_F)$ (see Appendix No. 1, equation 18).

It is apparent from equation 1 that an increase in the zero sequence impedance decreases the fault current as would, for example, an increase in R_N—the insertion of a resistance between neutral point and earth. The factor influencing the magnitude of the fault current is the ratio

$$k=Z_0/Z_1=\frac{\text{Zero Sequence Impedance}}{\text{Positive Sequence Impedance}} \quad \ldots\ldots(5)$$

Combining equations 1, 2, and 5, and substituting for $Z_1=Z_2$, we obtain

$$I_F=V^1\times d/(2+e+k) \quad \ldots\ldots(6)$$

or

$$I_F=I_{3\phi}\frac{3}{2+e+k} \quad \ldots\ldots(7)$$

where $d=3/Z_1$, $e=3R_F/Z_1$. Usually, it is justified to take $Z_1=Z_2$ for transmission lines, cables, and transformers. For generators Z_{2G} is considerably less than Z_{1G} but the assumption $Z_{1G}=Z_{2G}$ is justified because the generator impedances are only a small part of the total system impedances. For double earth-faults, assuming $e=0$, we get

$$I_F^1=\frac{3I_{3\phi}}{1+2k} \quad \ldots\ldots(8)$$

In a similar manner we can derive with the aid of symmetrical components (see Appendix No. 1) line-to-earth voltages at the point of fault.

$$V_R=\frac{V_R^1\times e}{2+e+k} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$V_Y=-\tfrac{1}{2}\sqrt{3}V_Y^1\frac{\sqrt{3}(k+f)+j(2+e+k)}{2+e+k} \quad \ldots\ldots (10)$$

$$V_B=-\tfrac{1}{2}\sqrt{3}V_B^1\frac{\sqrt{3}(k+f)-j(2+e+k)}{2+e+k} \quad \ldots\ldots (11)$$

where $f=R_F/Z_1$, $V_R^1=V_Y^1=V_B^1$=phase-to-neutral voltages.

Alternatively, we can obtain line-to-earth voltages V_R, V_Y, V_B under fault conditions by adding geometrically to the neutral displacement voltage V_N the phase voltages $V_R^1=V_Y^1=V_B^1$ existing under normal system conditions. According to F. L. Blume,[3] neutral shift expressed as a percentage of phase voltage is

$$\%V_N=\frac{100(k-1)}{k+2} \quad \ldots\ldots\ldots\ldots (12)$$

Take an example: For $k=1$, $Z_0/Z_1=1$, $R_F=0$, and $V_R=0$; line-to-earth voltages $V_Y=V_B$ are the same as under normal system conditions according to equations 9, 10, and 11. $V_Y=V_Y^1$ and $V_B=V_B^1$. Substituting in equation 12 for $k=1$, we see that the neutral displacement voltage is zero.

It follows, in the event of a line-to-earth fault where, say, red phase is involved and the zero sequence impedance is equal to the positive sequence impedance, $Z_0/Z_1=1{\cdot}0$, that assuming a delta-star connected transformer $Z_1=Z_2=Z_0$ with solidly earthed neutral, the phase displacement voltage V_N of the neutral becomes zero, and normal frequency phase voltages under fault conditions remain unaffected, as illustrated in the vector diagram, Fig. 3.

For $Z_0/Z_1=k=10$, $R_F=0$, we obtain from equation 9 $V_R=0$; equation 10 gives $V_Y=1{\cdot}5V_Y^1$; equation 11 gives $V_B=1{\cdot}5V_B^1$; and equation 12 gives $\%V_N=75\%\,V_R^1$. Thus the stresses on the healthy phases become 1·5 times the rated value (see vector diagram, Fig. 4).

In a similar manner we can derive, with the aid of symmetrical components, line-to-earth voltages at the point of fault for a double line-to-earth fault.

Solid earthing

Here no resistance is intentionally inserted between neutral and earth. The earth-fault current is restricted by the line impedance and fault path resistance and may exceed the 3-phase fault current, particularly in multiple-earthed systems. In this case a circuit-breaker will be required of higher rupturing capacity than for 3-phase fault. This follows from equation 7, namely the magnitude of the earth-fault current is equal, larger, or smaller than the 3-phase fault current, depending on whether the ratio $Z_0/Z_1=1$, <1 or >1, assuming that the X/R ratios of the positive and zero sequence impedances are close together.

For instance, for $k=1$, $Z_0=Z_1$, $R_F=0$, $I_F=I_{sc}$ the single-phase short-circuit current is equal to the 3-phase fault current.

The solidly earthed neutral ensures that voltages between healthy phases and earth will not exceed the rated phase voltage, because the neutral displacement voltage is approximately zero. In fact, solid earthing should be considered as an effective earthed system, because of the small value of R_0 compared with X_1. For $Z_0/Z_1<1$ we secure less favourable fault current conditions but favourable steady-state overvoltage conditions and hence less cost for system insulation. However, it is likely that the earth-fault current would be larger than the 3-phase short-circuit current, which will result in higher costs for switchgear.

For earth-faults at points remote from the source of supply, the ratio $k=Z_0/Z_1$ becomes larger, which results in higher steady-state overvoltages between healthy phases and earth (see equations 10 and 11), but in smaller earth-fault current than 3-phase short-circuit current.

Where an interconnected power system is fed from several sources of supply and earthed at one point only, or where the neutral point of one transformer is solidly earthed (partially solid earthing: see Fig. 1, Station A) the line-to-earth fault current and consequently the short-circuit rating of circuit-breakers can be reduced because of the increase of Z_0. However, it should be emphasized that the loss of a neutral earthing point during the period of system disturbances, resulting in a part of the system being left with, say, a line-to-earth fault, means that the insulated neutral may expose system insulation to hazard owing to generation of high voltage. It is well known that a capacitance current exceeding 5A maintains an arc in the ionized path of the fault; consequently there will be a risk of overvoltage conditions arising from arcing earth phenomena. The persistency of the arc maintained by the capacitance current enables cyclic charging and discharging of the system capacitance through the fault, which results in a build-up of high transient voltages to about five to six times (theoretically) normal values.

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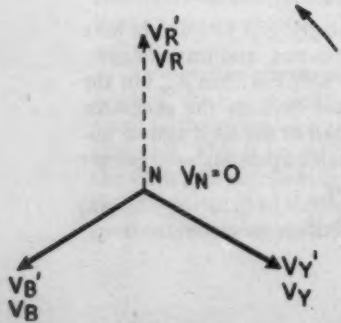


Fig. 3. System vector voltages subsequent to an earth-fault on phase R in a solidly earthed system.

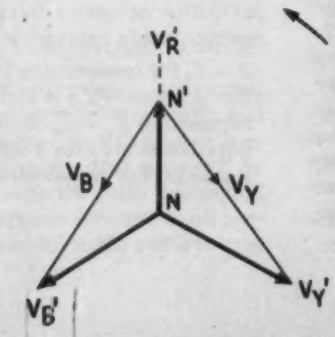


Fig. 4. System vector voltages subsequent to an earth-fault on phase R in a resistance-earthed system.

Corrugated Aluminium Sheathed Cable for Railway Feeders

THE ILLUSTRATION above shows the first length of A.E.I. 33kV oil-filled 3-core 0·30sq.in. aluminium conductor cable with corrugated aluminium sheath which has been installed for British Railways, Southern Region—near Brighton, Sussex. Laying was a night-time operation and the cable, hauled off train-mounted drums, handled very satisfactorily owing to the lightness of this form of construction. The weight of the served corrugated aluminium sheathed cable is 12·8lb/yd against 21·8lb/yd for the served lead sheathed cable with 0·30sq.in. aluminium conductors.

The work is part of a contract, valued at over £150000, covering the supply, supervision of laying, and jointing by the A.E.I. Construction Division of some twenty-four miles of 33kV oil-filled cable with aluminium conductors along various sections of the main London–Brighton–West Worthing line. The cable is to replace existing feeder cable and is laid into trackside concrete troughing.

A new 12-core plastic pilot/supervisory cable is also being installed along most of the route. It can be seen in the illustration being pulled off and bedded down alongside the 33kV feeder. The contract also includes supervising the transference of existing pilot cables from the wooden trunking in which they are at present laid to the new surface concrete troughing.

Earthing in Power Systems *continued*

Obviously, the loss of the system earthing point will result in a negative zero sequence reactance X_0, as the latter is predominantly capacitive. Hence the ratio X_0/X_1 is negative. Since R_0 is small compared with X_0 we obtain, from equation 5, $k=-X_0/X_1$ and the earth-fault current is small compared with the 3-phase short-circuit current.

On the other hand, the steady-state line-to-earth voltages of the sound phases are fairly large, owing to the negative value of k (see equations 10 and 11). At locations remote from the fault these voltages are still larger because of the larger capacitance current. Further, for $e=f=0$, factor k approaches (-2), i.e. when the sum of $X_1+X_2=2X_1=-X_0$ or $k=-X_0/X_1=-2{\cdot}0$ (series resonance), the steady-state voltage is for this case theoretically infinite.

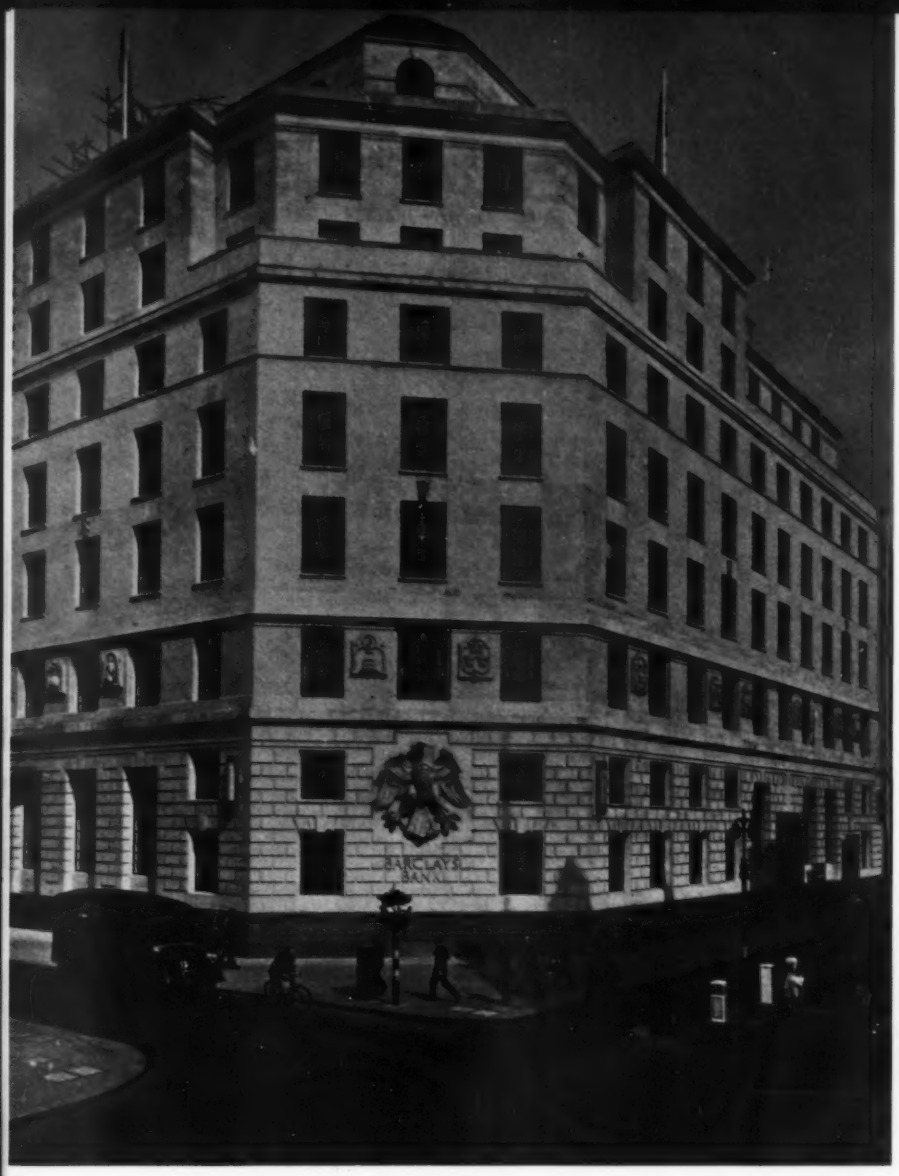
Summary. The main advantages of solid neutral earthing are

(a) use of power transformers with graded insulation, and
(b) reliable operation of the protective gear.

The disadvantages are

(a) circuit-breakers of higher rupturing capacity at locations near the source of supply, and
(b) possible damage to transmission elements at the point of fault owing to the large fault current.

References and Appendices will be included in Part 2, concluding this article, in the next issue.



The first stage of Barclays Bank's new head office in the City now graces the corner of Lombard Street. In this view of the building the two Siemens Ediswan City of London lanterns, specially manufactured in bronze, can be seen on either side of the Barclays' eagle.

Barclays Bank on A.E.I. Cables

MORE THAN SEVENTY-SEVEN miles of A.E.I. cables have been installed in the new Barclays Bank head office building in the City at the junction of Lombard Street and Gracechurch Street.

The rebuilding of the Bank's offices on this site is being carried out in three stages. The first stage, which occupies the corner site, is completed but the whole building will not be finished for several years.

The electrical contractors who are installing the A.E.I. cables are Messrs Drake and Gorham (Contractors) Ltd. The building has a three-channel underfloor trunking system: one is for the mains voltage cables, one holds the l-v internal telephone circuits, and the remaining channel accommodates G.P.O. telephone cables.

For the first stage of the rebuilding alone, some sixty

miles of v.r. cable have been used for the power and lighting circuits, and more than seventeen miles of telecommunication cables for the internal system have been laid and connected.

Recessed lighting has been used in most of the offices of this modern bank, using fluorescent tubes in fittings based on a 2ft module. An adequate supply of 13amp outlets caters for the many electrically operated accounting machines in use. A clock system with a master clock controlling slave dials ensures accurate timekeeping throughout the building, and a smoke detection system protects occupants from a possible outbreak of fire.

Provision has been made for a standby electricity supply for use in emergency by means of a 65kW diesel generating set which starts up automatically if the mains supply fails.

A second A.E.I. link with this new building is the 300h.p. motor of A.E.I. (Rugby) manufacture which provides power for the air-conditioning system, and yet another can be seen outside where, flanking the carved Barclays' eagle, two Siemens Ediswan City of London wall-mounted street lanterns have been fitted.

Architects for the whole rebuilding scheme are Sir Herbert Baker and Scott, F/F.R.I.B.A. Consulting engineers are Oscar Faber & Partners.

Proposed British Standards

THE ANNUAL REPORT 1959–60 of the British Standards Institution mentions, among other matters, the work of committees concerned with electric cables, distribution equipment, and overhead-line accessories which will result in new or revised future standards.

The new Standard being drafted to cover all armoured p.v.c. insulated cables, and the revision of B.S. 2004, *Unarmoured p.v.c. insulated cables*, received some criticism suggesting that the new Standard should be confined to cables required for public electricity supply, all other p.v.c. insulated cables being dealt with by the revision of B.S. 2004. It is hoped to resolve the difficulty by showing cables of special interest to the supply industry as preferred sizes and types.

A uniform system of voltage designation is being attempted for insulated cables. New requirements have been recommended for bending tests on paper-insulated cables to be included in the revision of B.S. 480.

Styrene-butadiene rubber is proposed as an alternative to natural rubber for general-purpose rubber insulation (amendment to B.S. 2899) and recognition of

Cabling Barclays Bank. *Left*, **installing lighting cables. The three-channel underfloor trunking can be seen.** *Right*, **installing A.E.I. telecommunications cables.**

butyl-rubber-insulated cables for buildings and strips is under consideration (amendments to B.S. 7 and B.S. 883).

A survey has been made of tests specified in current British Standards for electrical insulating materials with particular regard to deviations in like tests, and this is now being studied.

Tests proposed for insulator and conductor fittings for a new standard have proved to be unexpectedly stringent in practice, and have had to be recast.

A method of proving dust-tightness of enclosures has been developed by the E.R.A. for inclusion in a new standard, but a further report on cyclic heating and cooling conditions is awaited.

A draft is being prepared for a Standard on 62·5kV and 75kV (peak) cable terminations for X-ray equipment, providing for a cable termination interchangeable with that featured in a similar American Standard.

A revision of B.S. 196 covering industrial plugs and socket-outlets will include recommendations on the standard position of keys and keyways in the plugs and socket outlets in order to provide a means of discrimination between different types of supply (voltage, frequency, etc.) and different applications. Keys will also discriminate between plugs with or without fuses.

A revision of B.S. 2050, *Electrical resistance of conductive and anti-static products made from flexible polymers*, will take into account the resistance of both rubber and plastics materials.

Among items reported from the work of the International Electrotechnical Commission is the progress made on the second edition of I.E.C. Publication 92, *Recommendations for electrical installations in ships*. Quality requirements and testing techniques are included in the chapter on cables, and in a new chapter on protection the sub-committee concerned has compiled a code which will be a valuable guide for future ship installations, especially a.c. installations, which are now becoming more common.

The committee on electric cables has reached agreement on three complementary documents dealing with tests on gas-pressure and oil-filled cables for use at very high voltages, and drafts have been circulated to national committees for approval. Work has also been started on the revision of I.E.C. Publication 55, which deals with tests on solid-type paper-insulated cables.

It is now clear that the large majority of the European member-countries of the International Commission on Rules for the Approval of Electrical Equipment will accept green/yellow colouring either as an alternative to their present practice or as their sole national standard for the identification of the earthing core of flexible cords used for electrical appliances. A proposal to limit the colour to green only was not generally supported.

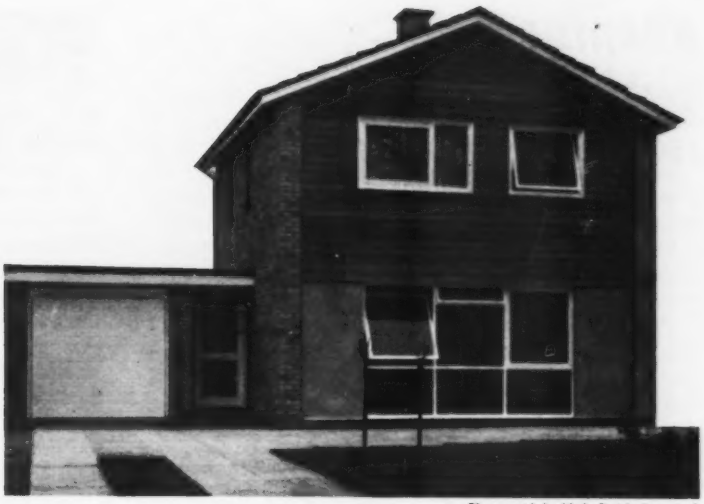
Cabling at Staythorpe "B"

WORK IS IN progress on the £¼ million contract for the cabling of the C.E.G.B. Staythorpe "B" power station which was awarded to A.E.I. last year.

Some of the cables which have been installed are shown in this picture of a general view of the west side of the cable chamber. The area runs the whole length of the station, providing cable access to 6·6kV and low-tension unit and station switchgear, and containing all control cables to the main control room.

Staythorpe "B" No. 1 generator is completed and is now in commission.

A.E.I. Wiring in a Show House



Photograph by H. L. Smith, Lowestoft

A SHOW HOUSE which was open to view at Old Catton, Norwich, earlier this year was selected by its builders, Ford & Carter Ltd, of Norwich, from the award designs in the Small Homes Competition sponsored jointly by *Ideal Homes* magazine and the R.I.B.A.

The house is design No. 601 by Mr Peter J. Ball, A.R.I.B.A., which he conceived as an ideal home for a young married couple. Electrical services have been allowed their due prominence in this three-bedroomed house, designed to fall within the price range £2 960–£3 460. Incidentally, the house was sold, furnished, before the period during which it was "on show" was completed.

The kitchen has a built-in refrigerator, and cooker control unit and allows space for washing-machine and spin-dryer. Clock points have been provided in kitchen and lounge. In the lounge, also, a TV socket has been fitted and wall-mounted lighting brackets have been used to provide the main illumination.

The electrical installation was carried out by E.C.A. member Frank Corner, of Norwich, using A.E.I. p.v.c. cable protected behind plaster with type B conduit. There is a total of thirty lighting points and eighteen 13A plug points throughout the house, split up into three ring mains. Electrical control gear and thermostats for a gas underfloor duct heating system were also installed.

Some 1 500yd of A.E.I. cables were used for the circuits, ranging from 3/·029 twin and 7/·029 to 7/·064 twin with earth continuity conductor.

25kV Railway Electrification

Cable Division developments and Construction Division activities shown at Battersea exhibition

THE BRITISH RAILWAYS' Electrification Conference at Battersea (3–9 October) was supplemented by an indoor exhibition at Battersea wharf. Here the important achievements of British 25kV railway electrification, as presented to delegates in the various technical papers, were emphasized by the equipment on view.

Among the exhibits on one A.E.I. stand were seen the cables and accessories which have been developed for the 25kV schemes by their Cable Division. Large photographs showed the activities of their Construction Division on various cable installation contracts carried out for British Railways.

The 25kV concentric conductor oil-filled cable which the A.E.I. Cable Division developed specially for the new schemes was shown, both in its original lead sheathed form and in the lighter corrugated aluminium sheathed design recently introduced. Delegates were also able to examine the oil-filled sealing ends and joints which were developed concurrently with the oil-filled cable. The 25kV solid type cable, installed on the Manchester–Crewe lines which were opened last month, was exhibited and examples of pilot/supervisory cables and track return cables were also displayed.

A.E.I.'s Construction (Cables and Lines) Division undertook the first installation of 25kV oil-filled cable at Stockport. The Division has also installed 10 800yd of this cable for the Glasgow Suburban electrification for British Railways, Scottish Region, and 24 000yd of solid type 25kV cable on the Manchester–Crewe lines. Illustrations showing these operations were featured on the stand, making an interesting background to the equipment displayed.

Keeping up with the Army

(90 miles of Cable help!)

ONE OF THE new-style military barracks at Colchester—the rebuilt Meanee and Hyderabad Barracks—is a far cry from the old-type Victorian barracks which demanded so much unproductive time spent in the form of "barrack chores".

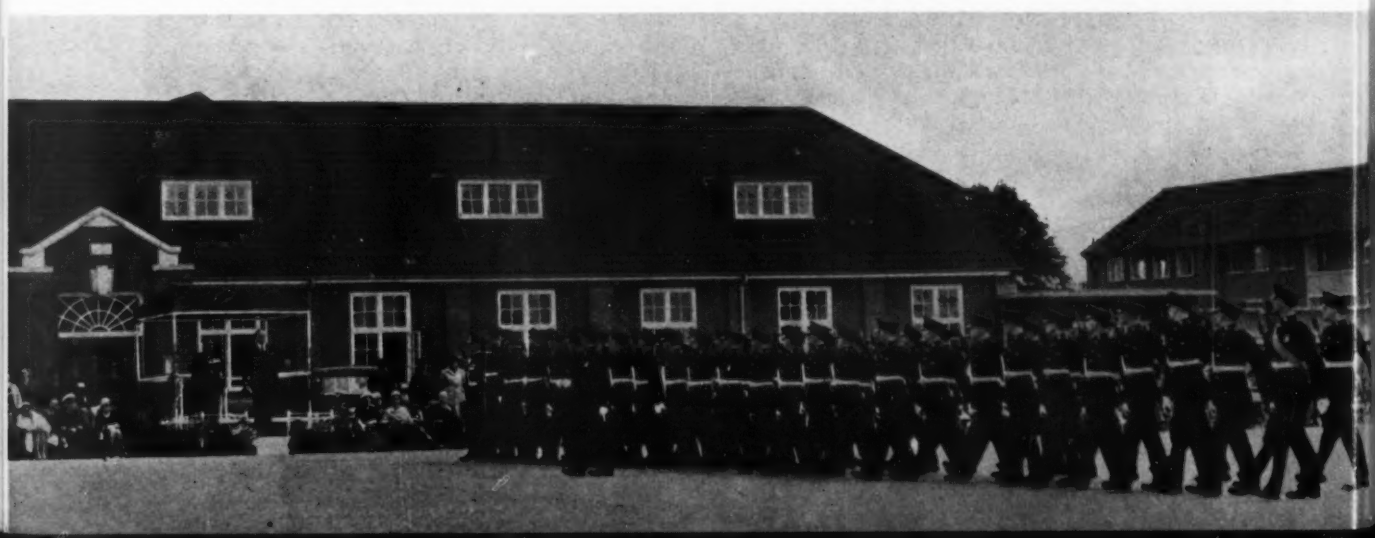
The barracks came into use a few months ago when the Duke of Wellington's and the Queen's Royal Surrey's occupied it—to find a standard of accommodation far higher than they had been used to in the past. Five three-storey blocks contain rooms for eight privates; each man has a hanging wardrobe, bedside table, mat, light, and bookshelf. On every floor there are baths, showers, toilets, and an equipment-cleaning room. In each block there are two lounges and the recreational facilities, both indoor and outdoor, are nothing less than excellent.

Modern electrical equipment, such as floor polishers, lighten the task of keeping the buildings spick and span, army style. The electrical installation is as extensive and up to date as can be found anywhere in the country. It was carried out by Messrs E. H. Ruddock Ltd, of Brightlingsea, who installed about 150 000yd of A.E.I. rubber-insulated cables and flexible cords of various sizes, and 8 000yd of paper-insulated, lead-covered, and armoured underground cables.

All the varied distribution equipment was of the "Henley" design, manufactured by A.E.I. As is to be expected in an installation of this size and scope, the equipment included feeder pillars, underground joint boxes, terminal boxes, service cut-outs, street lighting cut-outs, and many smaller accessories.

Part of the modernized barracks. The picture shows troops marching past the Rt Hon. Christopher Soames, Secretary of State for War, during the opening ceremony.

By courtesy of The Colchester Express



New British Standards

B.S. 3258:1960—Silicone Rubber Insulated Cables and Flexible Cords

This new British Standard covers a range of silicone-rubber-insulated cables and flexible cords in conductor sizes up to 0·06sq.in., suitable for a maximum conductor operating temperature of 150°C.

The specification is confined to single-core, twin, and 3-core cables and cords, finished either with glass braid and silicone varnish, or with asbestos braid and heat-resisting compound. The usual tests are included, with an additional heat-cycle test for single-core glass-braided flexible cords only. *Price* 5*s.* 0*d.*

B.S. 3249:1960—Cables and Flexible Cords Insulated with Varnished Cambric and Heat-resisting Fibre

This is a new publication replacing the part of B.S. 1327:1946 that dealt with flexible cords insulated with varnished cambric and asbestos. It includes cables and flexible cables, as well as flexible cords, for working voltages up to 660V and permits the use of glass fibre and polyethylene terephthalate fibre in place of asbestos fibre. The cables and cords are suitable for use in dry situations only, at a maximum conductor temperature of 85°C. *Price* 5*s.* 0*d.*

B.S. 3242:1960—Aluminium Alloy Conductors for Overhead Power Transmission

This new publication is expected to prove a useful addition to the range of British Standards for overhead line conductors. Its requirements are similar to those of B.S. 215 (which deals with aluminium and steel-cored aluminium conductors) but the new Standard covers a range of stranded conductors made of heat-treated aluminium-magnesium-silicon alloy in sizes from 0·015sq.in. to 0·4sq.in. copper equivalent. *Price* 4*s.* 6*d.*

B.S. 697:1960—Rubber Gloves for Electrical Purposes

This revised Standard (17 pp.) specifies requirements for gloves for use at four different voltage potentials: up to 650, 1 100, 3 300, and 4 000V.

A feature of the revision is that each glove is now required to be tested twice by the manufacturer for its voltage withstand. The second test has been introduced to seek out those gloves which have a tendency to pick up excess moisture, which reduces dielectric strength. Research work into this phenomenon has been carried out by the Electrical Research Association, who have taken an active part in the redrafting of the Standard.

An appendix to the Standard contains a series of helpful notes relating to the maintenance of the gloves after purchase.

Price 5*s.* 0*d.*

B.S. 3239:1960—Methods of Determination of Resistivity of Metallic Electrical Conductor Materials

This new British Standard prescribes the methods of determining resistance and resistivity to be used in reference and routine tests on metallic conductor materials. The accuracy of the reference method is as high as can be expected under laboratory conditions, and that of the routine method sufficient for most practical purposes. It is intended that the reference method should be used in any case of dispute. *Price* 5*s.* 0*d.*

Copies of these Standards may be obtained from the B.S.I., Sales Branch, 2 Park Street, London, W.1.

Our Readers Write...

MANY LETTERS HAVE been received from readers of long standing expressing appreciation of this journal's predecessor, *Distribution of Electricity*, and welcoming the new journal. Many copies, we know, are marked for "internal circulation" amongst the engineers and commercial staff of various companies. Frequently we have received requests for personal copies from individual readers who, in this way, have noted an article of particular interest to them and wish to file it for future reference. Such requests have encouraged us during past years in the production of this journal, and recent letters which readers have written to us have given us yet more encouragement in the preparation of future technical articles for the magazine in its new format.

Consulting and electrical engineers and libraries have spontaneously let us know of the past worth of *Distribution* to our readers in many countries—Portugal, Sweden, India, the U.S.A., Australia, and South Africa among them. Room has been found here for a few extracts from their letters but we hope that the great majority, whose letters do not appear, will, nevertheless, understand that their words of encouragement were greatly welcomed.

From N. S. Sethuramon of Sethuram Thiagarajan & Co., Madras, India

As one of the many readers, who have been acquainted with the journal *Distribution* for a number of years commencing from the year 1936, there is a deep sense of sorrow that the present issue that we have before us is the last one.

During this long period, the various articles dealing with transmission lines, cables, distribution equipment, and problems connected with general wiring have been of very great interest to us and, in fact, we looked forward with interest to the arrival of every issue... However, we congratulate the journal for entering into a new phase of life backed by a group of major industries. We hope that the journal will continue to be of great help to electrical engineers all over the world. We wish the new journal a continued success.

From L. S. Richfield, A.M.S.A.I.Mech.E., M.(S.A.) I.D.E., M.A.S.E.E., Stellenbosch, South Africa

I have received *Distribution of Electricity* for over twenty-five years and I cannot let the occasion pass without expressing my deep gratitude both for the valuable information contained therein but also for the other interesting and more social and amusing features.

You have my best wishes for the continued success of this magazine in its new form.

From G. E. McLean, B.Sc. (Eng.), Birmingham, 4

I should be very pleased to receive copies of the new journal, and would like to place on record my appreciation of the old journal, which I always found very interesting, and which was most useful to me as a part-time lecturer in electrical engineering work at the Matthew Boulton Technical College, Birmingham.

From F. E. Paice, Librarian of Humes Limited, Melbourne, Australia

We shall look forward to the receipt of ELECTRICAL DISTRIBUTION. Your previous journal has always been read with interest by our electrical engineers in the various divisions of this company. The technical matters discussed are of great value, and serve their purpose well —by keeping your customers advised of the latest improvements.

From C. L. de Beer, Director, South Wales Electric (Pty) Ltd, Johannesburg, South Africa

I have read your journal with very great pleasure over the many years, and while the new journal ELECTRICAL DISTRIBUTION will undoubtedly be of a very high standard and extremely interesting, it will not, I fear, have for many years that degree of intimacy which was such an attractive feature of your *Distribution*.

Editorial note: We shall try to keep our "intimate" approach, Mr de Beer, although familiarity with ELECTRICAL DISTRIBUTION *will doubtless increase as time passes.*

Book Reviews

Electromagnetic Fields, Energy, and Forces
By **R. M. Fano, Lan Jen Chu, R. B. Adler**

John Wiley (Chapman and Hall)

520 *pp.* *Price* 96*s.* 0*d.*

This book has been prepared by professors of the Massachusetts Institute of Technology with the objects of developing a consistent macroscopic theory of electromagnetism and investigating the relation between circuit theory and field theory.

The bases of the presentation are Maxwell's equations in integral form and the expression for the Lorentz force on a moving charge. The differential form of Maxwell's equations for fields produced by free charges and free currents and the associated boundary conditions are derived, and the action of stationary matter as a field source is discussed. The theory is developed through the concepts of electromagnetic energy and power flow, and Poynting's theorem is shown as the law of conservation of energy for electromagnetic fields. Finally, the macroscopic field laws and the associated power and energy concepts are extended to systems involving matter in relative motion.

The appendices include one on "Four-dimensional formulation of electrodynamics" which sets forth the relativistic macroscopic formulation of electromagnetism recently developed by one of the authors—L. J. Chu. Graduates and research workers should find it of great interest.

Cathodic Protection *By* **Lindsay M. Applegate**

McGraw-Hill Book Company

229 *pp.* *Price* 70*s.* 0*d.*

For a book which sets forth enough data for the understanding and practical application of corrosion prevention without delving deeply into abstruse technicalities the reader should turn to this volume. The author was a corrosion expert with the U.S. Army and the book embodies the material used on instruction courses for military personnel, since brought up to date.

The contents cover an explanation of corrosion and cathodic protection; the use of instruments and the significance of the results they record; the objectives and procedure of the survey; coatings, their advantages and snags; the use of various kinds of anodes to achieve desired results under the circumstances of the installation; and the design, construction, and maintenance of cathodic protection systems. A chapter is given to the protection of tanks and pipes in contact with soil and another deals with the protection of submerged structures under various conditions.

Books Received—

The Dynamic Behaviour of Thermoelectric Devices
By **Paul E. Gray**

Chapman and Hall

136 *pp.* *Price* 28*s.* 0*d.*

A research monograph which is the first published report of investigations into the small-signal dynamic behaviour of thermoelectric devices. Based upon work at the Massachusetts Institute of Technology.

Direct Current Electricity *By* **Alexander Efron**

Chapman and Hall

91 *pp.* *Price* 18*s.* 0*d.*

A nicely produced and explanatory student's first book on elementary d.c. theory, using the traditional Franklinian approach (+to−current direction). Problems at the end of each chapter. Card covers.

Cable Division Long Service

TWO EXECUTIVES OF the A.E.I. Cable Division recently completed forty years' service with the Company and each was presented with the traditional gold watch to mark the occasion.

First to receive his watch was Mr C. St L. Brightman, cable regional sales manager, Newcastle Branch. The award was made at the branch by Mr H. D. Parsons, divisional sales manager, in July. At a luncheon party held at the Royal Station Hotel, Newcastle, on the same day, Mr J. Bennett, director and general manager of A. Reyrolle and Co. Ltd, handed Mr Brightman an inscribed silver tankard and a diamanté brooch for his wife, as mementos of the occasion on behalf of some of his friends and trade associates.

The second executive to be presented with this symbol of long service was Mr R. B. Hill, joint home sales manager (Power, Rubber, and Thermoplastic Cables). Mr E. J. Vidler, divisional general manager, who had known Mr Hill since his schooldays, presented the gold watch at the Hatton Garden Offices of the Cable Division.

Mr C. St L. Brightman (*left*) receiving his gold watch from Mr H. D. Parsons.

At Mr R. B. Hill's presentation. Mr E. J. Vidler (*left*), Mr Hill, and Mr H. D. Parsons.